Cognitive Analysis of Decision Support for Antibiotic Prescribing at the Point of Ordering in a Neonatal Intensive Care Unit

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Abstract

Computerized decision support systems have been used to help ensure safe medication prescribing. However, the acceptance of these types of decision support has been reported to be low. It has been suggested that decreased acceptance may be due to lack of clinical relevance. Additionally, cognitive fit between the user interface and clinical task may impact the response of clinicians as they interact with the system. In order to better understand clinician responses to such decision support, we used cognitive task analysis methods to evaluate clinical alerts for antibiotic prescribing in a neonatal intensive care unit. Two methods were used: 1) a cognitive walkthrough; and 2) usability testing with a 'think-aloud' protocol. Data were analyzed for impact on cognitive effort according to categories of cognitive distance. We found that responses to alerts may be context specific and that lack of screen cues often increases cognitive effort required to use a system.

Introduction

Decision support systems that are integrated into a computerized provider order entry (CPOE) system can be one method of supporting accurate prescribing, particularly as the complexity of the prescribing task increases.[1] These systems frequently consist of alerts and reminders that provide clinicians with patient assessments and then guide them toward an appropriate course of action.[1] However, certain clinical tasks may impose excessive impact on cognition due to the complex nature and amount of information required to complete the task.[2] Prescribing antibiotics in premature infants is an example of a complex clinical task that requires knowledge of multiple patient parameters in a setting where rapid decision making is often required due to the risk of morbidity and mortality associated with sepsis in this population.[3] Methods of cognitive task analysis (CTA) have been used to inform the development of computerized systems that support human-computer interaction in complex tasks.[4] Existing systems may be used to evaluate available functions that can facilitate or hinder task completion by highlighting the cognitive processes required to use the interface in a particular domain.[4] In order to inform the development of a decision support system for antibiotic prescribing in a neonatal intensive care unit (NICU), we evaluated the current decision support capabilities in use within our CPOE system. Two CTA methods were used. A cognitive walkthrough which provides a step-by-step description of the use of a given interface for a specific task and a think-aloud protocol which allows for the exploration of clinician problem solving strategies while using a particular system.[5] The combination of these two methods has been recommended as providing information that is complimentary and therefore may be more informative than that can be gained by using either method alone.[6]

Background

Previous research on the cognitive effects of a CPOE user interface reported that the design of the interface can pose undue cognitive demands on the user, which can lead to error.[7] Design that is focused on reducing cognitive demand can be important in ensuring efficiency and preventing error.[7]

Methods of cognitive task analysis have been developed based on theories of human computer interaction.[4] Norman's Theory of Action was used to inform the current study. This theory proposes a cyclical model starting with a goal and progressing to generation of a plan of action, carrying out of that action, response by the system, and interpretation and evaluation of the response by the user, which in turn leads to generation of new goals.[8] Norman's theory uses the concept of a "gulf" to illustrate the gap between the goals of a user and the physical actions or affordances provided by a system to facilitate completion of tasks.[4] When users attempt to carry out tasks using a computer system, cognitive processes are required to formulate goals and to transfer these goals into actions required to use the system. The degree of mental processing involved in formulating an intention and determining how to use the system to meet a goal is referred to as the *gulf of execution* and the mental processing required to evaluate the systems response to actions is referred to as the *gulf of evaluation.*[8]

The term *cognitive distance* has been used to describe the degree and type of mental transformation required to bridge the gulf of execution and the gulf of evaluation.[9] Three types of cognitive distance correspond to the gulf of execution and the gulf of evaluation: semantic distance, articulatory distance and issue distance.[10] *Semantic distance* is the relationship between what the user wants to communicate and the meaning of the corresponding expression in the interface language. When concepts are represented directly in the interface, semantic distance is decreased.[10] When complex, ambiguous or vague icons or words are used to represent a concept, semantic distance is increased. *Articulatory distance* concerns the relationship between the meanings of the expression and their physical form. Physical form can be a sequence of keystrokes or mouse movements and clicks.[9] *Issue distance* represents the cognitive effort required when a shift in goal is necessary. Cognitive effort is required to understand that the original goal cannot be achieved or that a shift in goal is needed to achieve completion of the task.[8]

Methods

We used two methods of cognitive task analysis, the *cognitive walkthrough* followed by a *think-aloud protocol* in order to evaluate the current processes available and the related decision support in place for antibiotic prescribing in the NICU.

The cognitive walkthrough completed by the researcher (BS) under the guidance of an expert in cognitive evaluation methods (DK), identified goal-action sequences and the potential problems that may be encountered by users when carrying out their work tasks. We categorized specific problems encountered according to the three categories of cognitive distance to describe the impact on cognitive effort imposed by the current CPOE system and related DSS. Our goal was to identify recommendations for future systems that may reduce cognitive effort and facilitate completion of tasks. In both phases of the evaluation, two scenarios were used that required the completion of specific order entry tasks typical of those carried out in patient care situations in the NICU. During the think-aloud protocol, individuals with domain knowledge were asked to verbalize or think out loud as they carried out tasks. The act of carrying out a task prevents the participants from self-auditing and theoretically allows for the actual cognitive processes to be verbalized and captured.[11]

Two scenarios were developed based on information gained from focus groups with NICU clinicians. Both scenarios were validated by a domain expert with twenty years of experience in a NICU. Current alerts for antibiotics are described in Table 1.

Table 1. Antibiotic Alerts

Alert Name	Description
Aminoglycoside check	Provides time of last dose of any aminoglycoside
Laboratory history	Provides lab results for creatinine and drug levels
Renal impairment	Recommends dose based on renal function
Duplicate drug	Warns of repeat order
Pediatric dosing	Default dose/frequency based on gestational age/wt.

Procedures

Two scenarios, described below were carried out for both the cognitive walkthrough and the think-aloud protocol. The cognitive walkthrough was completed prior to the think-aloud protocol. In both phases potential problems were identified and classified according to impact on cognitive distances.

After IRB approval was obtained, neonatal clinicians were invited to participate in the study. Participants were recorded as they carried out tasks related to the following two scenarios:

> **Scenario A:** Infant with late-onset sepsis who must be started on vancomycin and gentamicin (choice of antibiotic was made based on current local practice). This infant had an elevated serum creatinine of 1.7, an intentionally elevated level designed to trigger an alert for renal impairment dosing and lab history.
>
> Task 1 – enter order for vancomycin
> Task 2 – enter order for gentamicin
>
> **Scenario B:** Infant with early onset-sepsis. Admission orders include gentamicin and ampicillin.
> Task - Enter orders using the NICU general admission order set.

Each of the subjects' interactions was then evaluated for usability issues identified by the walkthrough. Additional problems not identified in the cognitive walkthrough were categorized. Impact on cognitive load was evaluated by assigning identified problems to each category of cognitive distance. The coding framework was reached by consensus with two members of the research team. Recordings were obtained via Morae™ video-analytic software (TechSmith Okemos, MI.)

Setting: The study was conducted in the NICU at the Morgan Stanley Children's Hospital of New York-Presbyterian, Columbia University Medical Center, a quaternary care referral center serving a diverse population in New York City. Alerts within the CPOE are developed by the hospital alerts committee in conjunction with clinicians who request the alert and relevant content experts such as pharmacists.

Prior to implementing the CPOE system, a team of clinical pharmacists, pediatricians and nurses developed rules for pediatric and neonatal dosing for approximately 200 commonly used medications. The system provides default dosing, route and frequency suggestions based on the rules developed. Clinicians may accept or change default dosing suggestions. Alerts must be acknowledged but acknowledgement can be followed by either a change or cancellation of the order or by proceeding with the order as is. Order sets have been developed by NICU clinicians to address typical scenarios in which multiple orders are entered. The development version of the CPOE system was used by participants to carry out the tasks. No actual patient data were used.

Participants: Clinicians who had completed at least one rotation or who currently practice as a care provider in the NICU were eligible for inclusion.

Results

Participants

A total of nine clinicians, including three pediatric residents, four neonatal nurse practitioners (NNP), one pediatric hospitalist and one physician's assistant (PA) were recruited. Two of the NNP's had 20 years of NICU experience, one had 3 years experience and one had 2 years experience. Two of the residents were interns and one was a second-year resident. The hospitalist had 4 years experience and the PA had 2 years experience.

Cognitive Walkthrough Results

Task 1 in scenario A was to enter an order for vancomycin, while task 2 was to enter an order for gentamicin. Each order was entered individually. For the vancomycin order, ten sub-goals were identified, while seven were identified for the gentamicin order. The vancomycin order triggered three alerts, the aminoglycoside check, laboratory history and renal impairment dosing alerts. The gentamicin order triggered two alerts, the laboratory history and the renal impairment dosing alert. Both orders triggered the pediatric dosing support (i.e., default dosing, route and frequency suggestions) previously described. Nine usability problems were identified in scenario A. For scenario B, the cognitive walkthrough revealed two possible paths users might take when entering orders using the order sets. Each of these paths were mapped and coded for potential usability problems. For path i, sixteen sub-goals were identified to complete the task. Two alerts were triggered plus the pediatric dosing support. (Table 2). For path ii, fifteen sub-goals were identified and two alerts were generated. A total of thirteen usability problems were identified. Table 2 illustrates the number of sub-goals required for completion of each task in the two scenarios, the number of alerts and the number of usability problems identified in each scenario. Table 3 displays the specific problems encountered and the corresponding category of cognitive distance impacted by each problem. The most commonly occurring problems related to semantic distance (n=46), followed by articulatory distance (n=20) and issue distance (n=11).

Table 2. Results: Cognitive Walkthrough

	Task/	Sub-goals	Alerts	Dosing	Usability Problem
Scenario	Path	n	n	yes/no	n
A: Individual Orders	1	10	3	yes	9
	2	7	2	yes	
B: Order Set	1/i	16	2	yes	13
	1/ii	15	2	no	

Dosing –calculation with suggestion for dose and frequency based on weight and age with explanation.

Think-aloud Protocol Results

A total of eleven potential problems occurred across all participants in the think-aloud protocol. The most

Table 3. Identified usability problems from cognitive walkthrough and think-aloud protocol

Semantic distance	CW	TA	*Articulatory distance*	CW	TA	*Issue distance*	CW	TA
	n	n		n	n		n	n
Lack of screen direction	21	88	Unclear which button to select	9	1	Information timing inconsistent with user workflow	8	33
Poor screen layout	20	4	Drop-down list inconsistent with user task	4	3	Lack of provision for information follow-up	3	13
Unclear / erroneous information	4	58	Blank / inactionable fields	4	1	Repetitive information	0	23
Font too small to read	1	0	Excessive scrolling required	1	0	Information disagreement / mistrust	0	46
			Ambiguous / vague Icon	2	3			
Totals	46	150		20	8		11	115

CW- cognitive walkthrough, TA- think-aloud protocol commonly occurring problems were related to semantic distance (n=150) followed by those relating to issue distance (n=115) and articulatory distance (n=8) (Table 3). For all nine subjects, the most frequently occurring problem was lack of screen direction (n=88). Repetitive information was a common issue distance problem (n=23). The repeated information caused the users to re-read the same words which forced them to shift their goal. When the alerts repeated themselves clinicians were more likely to override them. As one subject stated: *"It gets you in the habit of clicking and just ignoring."* Information mistrust was observed 46 times, mostly associated with clinicians' disagreeing with or needing to verify the default dosing suggestions.

Although only 3 episodes were observed, drop-down lists were thought by users to pose serious problems. For example a user stated: *"These frequencies are not a very smart combination...you have to scroll very far down, when you're in a hurry, it's very, very hard.*" This illustrates an increase in articulatory distance, where the user has trouble carrying out the task using the interface. The types and frequencies of problems impacting each category of cognitive distance in the think-aloud protocol are illustrated in Table 3.

Overall, both scenarios provoked a similar number of problems. Scenario A had an elevated serum creatinine, which generated a need for users to make additional decisions that reflected frequent goal shifts, thereby increasing issue distance. Scenario B had a higher number of semantic distance problems due to the way in which alert screens are presented when using an order set. Specifically, in this CPOE system, when a clinician completes an order using an order set, all related alerts are presented at the conclusion of the order, with minimal screen direction. See Table 4 for results by scenario.

Table 4. Results: Think Aloud by Scenario

Scenario A				Scenario B				Overall
AD	SD	ID	Total	AD	SD	ID	Total	Total
3	55	77	135	5	95	38	138	273

AD-Articulatory distance, SD-Semantic distance, ID-Issue distance

Discussion

This study reports on an evaluation of potential usability problems users may encounter as they attempt to carry out complex tasks related to antibiotic prescribing in a NICU. The study used methods based on Norman's Theory of action. The cognitive walkthrough revealed information about screen usability while the think-aloud revealed clinicians' interactions with decision support tools at the point of care. The cognitive walkthrough revealed more screen navigation problems corresponding to increases in semantic and articulatory distance and the usability testing revealed more problems related to the information contained in the screens – 'how does this information help me do the task', resulting in more increases in issue distance. According to Hutchins et al., a mismatch between the goals of the user and the physical actions afforded by the system, increases cognitive distance.[9] Impact on cognitive load is directly related to impact on cognitive distance, therefore these demonstrated increases in cognitive distances indicate an increased impact on cognitive load imposed by the system. The problem of unclear screen directions, the most frequently occurring problem, is an example of a discrepancy between the goals of the user and the affordances provided by the system. Cognitive theory posits that human beings develop mental representations or models of tasks. [4] When a users mental model of the task is mismatched with the representation of the task in the system, a transformation must take place resulting in increased cognitive effort needed to complete the task.[4] The elevated serum creatinine in scenario A introduced an increase in task complexity. The need to address this issue required users to alter their initial prescribing decisions, reflecting a need for a goal shift, which increases cognitive load by impacting issue distance.[8] Frequent goal shifts may impose a potentially heavy cognitive burden.[8] The use of individual alert screens that provide pieces of information throughout the course of task completion required that users had multiple goal shifts to deal with the information as they carry out tasks. In order to reduce this impact on cognitive burden, it may be helpful to present needed decision support in such a way so that all the information required to complete the task is represented in a more comprehensive manner.

Specific alert screens were also associated with a lack of information clarity, undesirable information timing and lack of provision for follow-up, which created increases in semantic and issue distance. Van der Sijs et al., recommend that information be presented in a clear, concise format with actionable choices, with the goal to prevent error producing conditions that can lead to active failures such as medication errors.[12] The impact imposed on cognitive load may provide an explanation for the relationship between these error producing conditions and resultant active failures.

In our study, multiple orders were entered in a single session, however, each antibiotic order triggered the same alert causing the clinician to view the same information repeatedly. When an alert was repeatedly triggered, clinicians were more likely to 'click through' the alert. Repeated alerts may result in high override rates; however, override rates may not fully reflect the clinician's response to the information contained in an alert. Instead, clinicians may have noted the information when they first viewed it, and thus the subsequent presentation may be considered irrelevant. Therefore, relying on override rates alone may not accurately capture whether or not the clinicians registered the information.[13] Additionally, when an alert did not apply to the specific situation, the clinician did not pay attention to it. In contrast, an alert that specifically applied to the situation in this study was the renal impairment alert which caught the clinician's attention because the baby's creatinine was 1.7 mg/dl, a very high level. Other studies of override rates have also found that clinical relevance plays a role.[13]

Our clinicians frequently cited the need to verify the suggested dose because they were not sure if the recommendation was correct for that specific patient, given the context. When the clinicians' calculation did not match the recommendation, the clinician changed the dose or frequency. Although we did not calculate override rates, other researchers have reported high override rates of computerized pediatric dosing suggestions.[14] When calculating their override rates, it is possible that the decision support in the study did not take patient context into consideration.

Limitations

This study took place in an academic medical center located in a major metropolitan area. Results may not be the same in other locations or in non-academic medical centers where processes followed to enter orders are not the same. We also used a commercial CPOE product that is part of a clinical information system. Results may be different in other systems.

Conclusion

This study evaluated the impact of clinical alerts on cognitive load by assessing increases in cognitive distance. Different usability problems corresponded to different types of cognitive distance. Improving screen design, by providing clear direction through the use of salient cues in the interface may reduce cognitive effort by reducing semantic and articulatory distance. Reducing redundancy of alerts and providing updated, clinically relevant information synthesized into one easily accessible screen may reduce issue distance, allowing clinicians to stay focused on the task at hand. Understanding how decision support tools impact cognitive load provides us with a method for improving our understanding of how these tools are used in specific patient care situations. Combining this with other evaluation methods may be helpful in providing a more complete understanding of the effect of decision support on clinical care.

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